EVALUATION OF PINE BARK BEETLE INFESTATIONS IN THE SIERRA FRIA, AGUASCALIENTES, MEXICO

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BACKGROUND

USDA-Forest Service, Forest Health Protection (FHP), sent two forest health specialists to Aguascalientes, México 4-6 July, 2001 in response to a technical assistance request from the Asociación Sierra Fría, A.C. (ASF), routed through the U.S. Embassy, México, D.F. The purpose of the trip was to view and evaluate infestations of pine bark beetles and recent control measures. FHP International Activities Team sent Dr. Stephen Clarke, FHP bark beetle specialist, Southern Region, and Gary K. Smith, Integrated Pest Management (IPM) Specialist, Pacific Northwest Region to consult with local managers of the Asociación Sierra Fría, A.C. (ASF), in Aguascalientes, México on current control tactics and future management strategies. A particular emphasis of the Asociación is to identify IPM strategies that may prevent or interrupt bark beetle infestations with biologically-based controls such as augmenting natural enemies or using pheromones.

In addition to our hosts Alberto Perez and Clemente Villalobos, ASF, we were joined other ASF members, and diverse Mexican biologists from federal and state governments, universities, and biocontrol industry. Representatives of both SEMARNAT and the Comisión Nacional Forestal participated in the consultation.

We began with welcomes, introductory presentations, and a press conference at the Universidad de Aguascalientes. Afterward, we drove to the Sierra Fría conservation area. During the next two days:

We visited numerous pine stands, reviewing infestations of *Dendroctonus* spp., most of which had been sanitized 3-4 months previously.

We installed four Lindgren funnel insect traps in each of two stands that experienced post-sanitation bark beetle attacks. Two traps of each foursome were baited with Frontalin attractant (aggregating pheromone). The remaining two traps were baited with both Frontalin to attract bark beetles, and Verbenone repellant (anti-aggregating pheromone). Differences in trap collection counts between the treatments may indicate an effect of Verbenone on native bark beetles under summer conditions.

We visited a local pine nursery and discussed nursery pest control and reforestation challenges in the Sierra Fría.

We discussed bark beetles, pines, the Sierra Fría ecosystem, the management system and objectives of the ASF, and research needs, summarized in this report.

ENVIRONMENTAL SETTING

The Sierra Fría ecosystem is an island of forested mountains surrounded by semiarid grass/shrublands, located in the northwest quarter of Aguascalientes state. The Sierra contains ingeous and metamorphic rock types. Elevations range from 2,000 to 3,000 meters above sea level. Annual precipitation averages 600 millimeters. The watersheds of the Sierra Fría are a major and critical component of recreation, irrigation, and municipal water supplies for Aguascalientes state and capital city.

In the 112,090 hectare "Area Natural Protegida" of the ASF, three forest types comprise the 76,000 hectares occupied by woody plants: mattoral (shrubland); encino (mixed oak); and pino-encino (mixed pine and oak). Just 8,000 hectares of the ANP contain a significant pine component; inventories indicate about 800,000 pine trees in total. Six pine species are present in mixed stands, generally located on sheltered slopes and valley bottoms with favorable moisture conditions.

Landownership is about 70 percent private and 30 percent ejidal (communal). We did not visit with any representative of the ejidos. ASF hosts indicated that ejidal management focuses more on short-term economic-driven land use, including more intensive grazing. However ejidos are principally located on mesalands without a substantial pine-oak component.

Local scientists believe that pine forests and disturbance patterns were substantially altered by human activity from the 1920's through the 1950's, when some areas of pine-oak forest were intensively harvested for charcoal and lumber. There have been no significant wildfires in the Sierra Fría since a 300 hectare wildfire in 1940. In the 1960's, gas became available and exploitation of the Sierra Fría for wood products ended. A confluence of economic events and prolonged drought in the early 1980's caused grazing to decrease substantially. Land ownership since that time has shifted to privately-owned recreational, conservation and hunting preserves. Many landowners are members of the ASF.

ASF has organized and led landowners of the Sierra Fría in cooperative efforts to improve conservation of the ecosystem. The development of a public checkpoint and patrol system has minimized unauthorized forest exploitation, allowing for effective landscape-scale conservation to be realized. With secuestration of firearms, access control, and patrol, landowners do not view unauthorized hunting, logging or grazing as significant problems. ASF also has established notable positive relationships with political and regulatory entities and cooperative studies with universities and other research institutions.

A severe drought beginning in 1981 was a major factor in land use changes. People remember a large amount of pine mortality in 1983-84 due to bark beetle infestations, and a comparison of aerial photos taken earlier and later shows a notable reduction in pine forest cover. In some infested areas trees were harvested and removed, or sanitized using similar treatments to today.

Another drought began in 1993 and has continued almost until today, the Sierra Fría receiving about sixty percent of mean annual rainfall. Recent above-average rainfall has provided some water stress relief and may be the harbinger of a return to wetter conditions.

Changes in pine-oak forest structure and composition portend future reductions of pine populations. Overstory pines average about 80 years of age. We saw a nearly complete absence of pine regeneration throughout the large number of pine forests we visited. Without seedlings as replacements, every pine that dies is a loss to a limited pine resource and those resident and migratory species who depend on pine habitats. Instead we observed increased oak coverage and frequently a prolific invasion of táscate juniper (*Juniperus deppeana*). Possible reasons for the lack of pine reproduction include a competitive shrub oak understory, absence of fire site preparation, limited cone production, cone serotiny and/or seed viability, seed predation, and juniper competition/allelopathy.

INFESTATION AND CONTROL HISTORY

The drought that began in 1993 was followed by annual losses to bark beetles (*Dendroctonus spp.*) of 1500-2000 pines per year between 1995 and 2000. In January, 2001, more extensive mortality began to be noticed by landowners, patrol crews, SEMARNAT staff, and researchers. Starting in February 2001, an emergency sanitation/salvage program began that has cut about 12,000 trees to date. Spots range from 10-90 trees (average 20-30); the largest infestation contained 300 trees. An infested tree turns to red in about 45 days from first infestation. The time interval from discovery to treatment averaged four to fifteen days. Still, crews noticed that there were sometimes trees already vacated by adults by the time of treatment. We observed the followup search for new attacks from the post-sanitation generation and sanititation operations. The number of new infested trees appeared to be greatly reduced, compared to the losses in the December 2000 to March 2001 initial attack.

Under Mexican law, landowners are required to cut infested trees upon receiving authorization from SEMARNAT. The costs of sanitation are borne by the landowner.

The authorization contains the steps required in the sanitation process:

> Discovery. Land owners, reserve guardians and patrols, SEMARNAT and cooperating agency pesonnel may identify spot infestations from road survey or aerial reconnaissance. They report to the ASF and/or SEMARNAT staff.
>
> Mark Infested Trees. Only authorized agents of SEMARNAT may mark trees to be cut. Once marked, landowners are obligated to cut them and remove or follow sanitation protocols.
>
> Fall and Remove Infested Trees. Landowners hired and coordinated 8 sanitation crews to complete the treatments. Logs were removed initially, until the purchasing enterprise went out of business.

Treat Infested Material Left On Site. Thereafter, felled trees were debarked on site and the bark was either burned, or all bark and wood surfaces were sprayed by a backpack sprayer with the insecticide Desis (deltamethrin). About half the treatments included a fungal additive *Metharhyzum anysoplae* to increase larval mortality. Slash pieces, if not treated, should be moved away from uninfested pine trees.

We also noted that Mexican law requires federal authorization for cutting of living trees, and may be a lengthy and inflexible process. This process may limit a land owner's ability to control larger infestations using a felled buffer strip technique (page 6).

ANALYSIS OF THE CURRENT SITUATION

All of the *Dendroctonus* caught in the funnel traps during our brief visit were *Dendroctonus mexicanus*. This species is normally not as aggressive as some other *Dendroctonus* species such as *D. frontalis*. However, *D. mexicanus* has several generations per year, and when generations begin to overlap, expanding infestations may develop. We also observed some larger galleries in the infested trees that had been felled previously. Based on a conversation with Dr. Pat Shea, Research Scientist Emeritus with the USDA Forest Service, these infestations were probably caused by *Dendroctonus adjunctus*. This species has been trapped in the Sierra Frias, and is usually the beetle responsible for mortality at higher elevations. *D. adjunctus* has one generation per year, and infestations therefore are usually small. A small amount of mortality from endemic populations of these species is expected annually.

Currently the actions of the two species are those of secondary bark beetle pests in outbreak status. The Region has suffered through an extended period of drought, and the beetles are responding to the weakened condition of the pines. As host resistance decreased due to drought, the number of suitable hosts increased, allowing beetle populations to build gradually. The forest structure in most areas is not conducive to the development of large expanding infestations except when high beetle populations are present; so most infestations are limited in size. However, the large number of small spots through time has severely reduced the pine component in the area. The absence of pine regeneration that we observed throughout the Sierra Fría threatens the long-term sustainability of pine-oak forests and the resident and native organisms which depend on this forest oasis

PREDICTED FUTURE TRENDS

The current level of bark beetle activity in the Sierra Frias leads to two possible scenarios for the future. In the first scenario, environmental conditions improve, tree resistance increases, and bark beetle populations begin to subside to endemic levels. This is typically the case with secondary bark beetle outbreaks. Though the scattered pockets of dead trees produced by such outbreaks initially appear catastrophic, in the long run the overall forest health is improved. Bark beetle attacks remove weak trees, (and some otherwise healthy), reduce pine tree density, and diversify forest species composition. The residual pines are usually more vigorous. However, any improvement in forest structure assumes that sufficient pine regeneration is available. Without adequate regeneration, even small sustained outbreaks of secondary pine bark beetles can lead to eventual loss of the pine component of the forest.

In the second scenario, the current activity signals the onset of a major bark beetle outbreak. Beetle survival is high, and populations begin exponential increase. The mode of action may switch from secondary to primary pest. Sufficient numbers of beetles are available to overcome the defenses of normally resistant pines, and large-scale infestations occur. Though natural enemies and other factors will eventually lead to a collapse of the outbreak, most of the pine may be killed.

Though the potential for a continued outbreak exists, our observations indicate that the first scenario is the most likely to occur. If the frequent rains that have fallen this summer continue, restored soil moisture should reduce some of the drought stress. The continued application of direct control should also help keep populations numbers in check, provided that prompt detection is achieved.

RECOMMENDATIONS FOR SHORT-TERM ACTIONS

We recommend that the association continue their program of felling the infested trees. Direct control of infestations is best method to reduce the loss of additional trees. Vigilant detection and prompt treatment are essential in direct control. If infestations are detected early, fewer trees are infested and treatments are smaller. Direct control requires felling of the infested trees. All currently-infested trees should be felled. Trees should be felled toward the center of the infestation, away from uninfested pines. Infested pines should be felled before the brood adults emerge. To preserve natural enemy populations, older attacked trees should not be treated if the adult beetles have departed.

We suggest four methods of direct control for use at this time. All can be effective in infestation suppression when applied properly. The tactic selected will depend on infestation size, location, environmental conditions and concerns, local timber markets, availability of labor, and/or other factors.

1. Cut and remove. Ideally, remove the infested material from the site immediately after felling. Removal eliminates the need for labor-intensive treatment of the felled trees. Removal is the most effective means of control.

If immediate removal is not possible, the infested material should be moved away from uninfested host trees and one of the following treatments applied.

2. Cut-and hand-spray. Fell the infested trees and buck them into workable sections. Thoroughly spray the bolts with an approved pesticide. Pesticide mixed with diesel provides the best penetration and may aid in killing the beetles before they emerge. Pesticides mixed with water often kills the beetles after they emerge, and emerging beetles may be able to participate in attacking new trees before they die. Pesticides will also kill beneficial insects, which may prolong the outbreak.

3. Cut-and-debark. Another alternative is to debark the infested trees. The bark may then be burned, buried, treated with pesticide, or wrapped in plastic and fumigated. A chipper could also be used to chip up the infested bark and branches. Transport the chip material to an area without suitable hosts.

4. Cut-and-leave. Fell infested trees away from uninfested trees and leave them in place. This tactic usually requires high mean daily temperatures above 28^{o} C. It is most effective when then early brood stages are present. It may also work best for bark beetle species with long developmental periods. It is suggested that this tactic be tested on small spots or for a few trees throughout the year before it is applied on a wide scale. Place emergence traps on the felled trees to test the effectiveness of cut-and-leave in reducing beetle survival. A buffer strip is normally also felled for this treatment. If the infestations are not expanding rapidly and the infested trees are felled away from uninfested trees, a buffer strip may not be required.

The following two tactics may also be employed at this time.

Mass-trapping. In addition to the felling of currently-infested trees, use funnel traps baited with bark beetle lures to reduce beetle populations and increase the efficacy of the treatments. Locate traps near the felled infestation, but away from any uninfested pines. If the traps appear very effective in catching beetles, then it might be possible to use traps in place of debarking. Mass-trapping has not received thorough testing and should be used with caution in order to avoid concentrating beetles that would increase and prolong the infestation. If effective infestation suppression is required, mass-trapping should only be used in conjunction with other direct control methods.

Monitor. The final alternative is to do nothing, allowing the infestations to grow or collapse on their own. It is possible that the current outbreak could subside without direct control. However, the potential for extensive tree loss exists if direct control tactics are not applied.

OTHER METHODS OF DIRECT CONTROL

Adding a buffer strip of uninfested trees when applying direct control tactics . If large, expanding infestations begin to develop, felling only the currently-infested trees will not be effective. Numerous breakouts would be expected. In this severe type of infestation, the association should seek authorization to cut a buffer of uninfested trees around the expanding "head" of the spot when applying the four direct control treatments previously described. The buffer disrupts the pheromone source at the expanding edge of the spot. Though some uninfested trees are sacrificed, the amount of total tree loss will be reduced greatly. Debarking or spraying the uninfested trees is neither necessary nor recommended.

Experimental applications of pheromones or other semiochemicals. Two tactics, verbenone-only and verbenone-plus felling, have been developed and validated for disrupting southern pine

beetle infestations in the USA. However, verbenone has not been tested nor registered for use in Mexico: experimental applications should be designed to obtain the data needed for the registration and effective use of verbenone. A push-pull technique, in which verbenone is applied around the spot head while vacated trees are baited with bark beetle attractants may disrupt infestation growth. Baited funnel traps could replace the baited trees in a variation of this control method. These tactics have not received adequate testing, and should be applied with caution, first in an experiment with a sound design. Attractants such as frontalin may also be used to steer expanding infestations into non-host areas, causing the spot to collapse. Research continues on the use of bark beetle deterrents such as green-leaf volatiles and 4-allylanisole in infestation disruption.

Maintenance of natural enemy populations. Natural enemies and competitors are thought to be a major factor in the collapse of bark beetle outbreaks. It may take several years for populations of natural enemies and competitors to reach levels that can exert control on bark beetle numbers. Therefore it is essential to preserve or even augment natural enemy populations. Limit the use of insecticides to infested trees with living broods of bark beetles inside. Leave pines vacated by bark beetles standing, as predators often have longer developmental times than their prey. These snags also serve as nest trees for woodpeckers that can feed on *Dendroctonus* larvae and pupae. Encourage the growth of plants that can provide nectar sources for bark beetle parasitoids. Methods of mass-rearing predators and parasitoids for augmenting populations are in development.

Other management actions. In addition to direct control of beetle infestations, any practices that serve to increase the health of the forest and vigor of the pines should be applied to help reduce the impacts of the current outbreak. (see prevention in the next section). However, thinning, burning or other activities that may cause short-term stress on the residual pines may be risky when applied during a bark-beetle outbreak. It may be more prudent to postpone hazard-reduction treatments until after the outbreak subsides.

Recommendations for long-term solutions

As our Mexican colleagues recognize and emphasized during our visit, we need to better understand the natural processes of the forest ecosystem in the Sierra Fria. With greater knowledge, a sustainable management plan can be developed for the ecosystem. As long as pines are a major component of the forest structure, there will be some mortality from bark beetles. Thus, we recommend two foci for investigation and action: develop an IPM (Integrated Pest Management) program, and develop a reforestation and vegetation management plan for the pine-oak forest.

Development of an IPM program for pine bark beetles

An IPM program is an essential part of the management plan. An IPM program for bark beetles generally consists of five components: prevention, prediction, detection, direct control, and area-wide control. We suggest the following specific IPM strategies for long-term bark beetle management in pine-oak forests of the Sierra Fria.

Prevention. Prevention of extensive bark beetle mortality is the cornerstone of the IPM program. Management practices that promote the vigor of the pines reduce bark beetle mortality. Selecting the appropriate species of pine for the site is essential. Thinning dense stands of pines reduces the hazard to bark beetles and restricts the potential of spread of incipient bark beetle infestations. Maintaining a mix of pine and hardwoods helps prevent the establishment of large infestations. Prescribed burning at the appropriate intervals can also improve forest health, increasing the resistance of the pines to attack.

Prediction. Predicting the onset of a bark beetle outbreak will allow managers quickly to marshal the resources necessary to control infestations and to take steps to reduce potential impacts. Funnel traps are traditionally used to monitor bark beetle populations. Baited traps are set out during periods of beetle dispersal. The average catch per day and the ratio of beetles/clerids are used to make predictions of expected activity. Other factors such as average rainfall or temperature patterns may prove useful in predicting population increases or decreases. An accurate prediction system may take several years to develop.
Another important component of prediction is the determination of which infestations will continue to expand. All infestations with currently-infested trees should be treated if possible. If available resources limit the number of infestations that can be controlled, then a prediction system or model is necessary so that managers can select infestations for treatment. Only infestations with a high probability of continued expansion would be treated.

Detection. Prompt detection of infestations reduces tree loss and increases the effectiveness of controls. Locating infestations is normally dependent on detecting changes in foliage color. In small mountainous areas with a good road system, drivers can spot most infestations. Possible infestations should be reported and ground-checked immediately. In larger areas, detection flights may be necessary. The timing and frequency of flights is dependent on beetle activity and environmental conditions.

Direct Control. Prompt control of bark beetle infestations is vital in limiting tree resource loss. When beetle populations are high, infestations should be prioritized for control. Large, expanding infestations are highest priority and should be treated as soon as possible. Small infestations of 10 infested trees or less may become inactive without treatment. However, in areas where the number of pines or pine regeneration are limited and the maintenance of the pine component is desired, any infestation with currently-infested trees should be treated. Do not treat trees that have already been vacated by bark beetles.

Area-wide Control. Area-wide suppression includes strategies that reduce the impacts of SPB outbreaks on a landscape scale. The goal is to limit the duration, frequency, and/or intensity of SPB outbreaks. The methods of area-wide control most commonly utilized are direct control of infestations and maintenance of natural enemy populations. Direct control, particularly when applied when beetle population numbers are low, may significantly reduce overall population levels. Maintenance of natural enemy populations is accomplished by leaving trees vacated by bark beetles in place and by limiting the use of insecticides. These techniques should be incorporated into the IPM program for the Sierra Fría.

Other biological control tactics have been suggested for area-wide control, but have not received sufficient testing. They include:

Natural enemy augmentation. Mass rearing and release of parasites and predators

Supplemental food sources for beneficials. Providing nectar sources or artificial food for natural enemies.

Trap trees. When bark beetle populations are very low, trees are baited with attractant during the beetle dispersal period. Attacked trees are felled and removed before the adults emerge.

Applications of pathogens. Diseases or pathenogenic fungi are applied to beetle infestations, and they spread throughout the population.

Research and field-testing are necessary so that promising new biocontrol tactics can be identified and developed for integration into bark beetle IPM programs in the Sierra Fría.

Development of a reforestation and vegetation management plan

A reforestation plan would identify goals for establishment of new vigorous pine seedlings in pine-oak forests of the Sierra Fría. Strategies to be evaluated include both natural and artificial regeneration: factors that influence the appropriate tactics and their effectiveness would be discussed. In the Sierra Fría, some ecological studies have already been done, however many details needed for the reforestation plan are unknown.

Another related ecological concern is the expansion of táscate juniper in both pine-oak and oak ecosystems. The environmental effects of táscate invasion and potential control strategies have

implications for all resources of the sierra, and the habitats and species that depend on them, including the citizens of Aguascalientes and beyond.

Openings created by recent bark beetle sanitation provide an ideal opportunity for study of natural pine reforestation processes, barriers to natural and artificial pine regeneration, juniper invasion, and seedling and site management techniques for pine establishment. Preliminary studies should be installed in this first year after sanitation. The USDA-Forest Service has technical experts who could potentially assist in developing plans for pine reforestation and táscate management, and in designing and installing studies.

Information and research needs

Numerous avenues of investigation, development, and field trial emerged in our collaborative on-site discussions. We also realized the long term solution to sustaining these forests lies in a management plan based on science. The ASF wants to develop such a plan. Studies of bark beetles, their pine hosts, and ecological interactions are all needed to support ASF in developing a management plan for the Sierra Fría reserve.

It is important to determine the species composition of the current bark beetle outbreak. An examination of felled, infested trees can reveal what beetle species are present, the portion of the bole they occupy, and the tree species they attack. Funnel traps can be used to capture and identify the bark beetle species, plus determine the peak diel and annual periods of flight activity. Such trapping can also reveal when traps should be deployed to predict coming population trends. Through long-term monitoring, it may be possible to relate bark beetle outbreaks to environmental conditions, increasing the forecasting capability and the readiness of the forest managers.

Once an infestation is initiated, it is imperative to understand the stand and/or environmental conditions that can lead to spot spread or collapse. Pheromone or other semiochemical research may provide alternative methods of control to felling of trees. There are many potential candidates that may prove useful. Extensive testing in areas of concern will provide efficacy and effects data needed to support pheromone use in preventive management of pines.

An interdisciplinary group should develop a preliminary reforestation plan that identifies goals for establishment of new pine seedlings in pine-oak forests of the Sierra Fría, and missing information and studies needed to field evaluate strategies and tactics. Strategies should include both natural and artificial regeneration: and the factors that influence the effectiveness of tactics. Include a vegetation management plan for pine interrelationships with táscate juniper and chaparrito oak. Studies should be initiated, this year if possible, of pine reproduction, competing vegetation, and interactions with site and climatic conditions to begin to identify factors that have limited the success of natural regeneration. With new suppporting data, the Sierra Fría management plan can encourage activities to reduce the identified limiting factors.

- Areas of investigation include:
- Pine cone and seed characteristics
- Vegetative competition and control for reforestation
- Invasive species management—táscate juniper
- Animal damage and control
- Artificial regeneration; nursery propagation and planting techniques

We were very impressed with the knowledge and expertise of forest biology scientific community in Aguascalientes. We recommend that the Association continue to collaborate with the Universidad de Aguascalientes, state and federal agricultural and forest health agencies, and other research institutions in México to understand the current and future impacts of pine bark beetles in the Sierra Fria. The ASF is well-organized, with a long record of forest restoration and conservation in the Sierra Fría. ASF is also considering organizing as a foundation in order to potentially qualify for additional sources of technical and financial support.

We believe that the Sierra Fría conservation reserve as managed by ASF constitutes a priority area for investigation and implementation of IPM, reforestation, and invasive species management. Both its situation and the organization effectiveness in protection and implementation are exceptional. The USDA-Forest Service has a network of experts in developing natural resource management plans, and in consulting and designing studies to address the investigation topics. We recommend that ASF should receive followup technical assistance as outlined above, and where appropriate financial assistance in conservation management studies and implementation. Additionally, USDA-Forest Service could help put ASF in contact with non-governmental organizations whose missions and programs are aligned with the Sierra Fría reserve programs for potential longterm cooperation and assistance.

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